Ecole et Observatoire des Sciences de la Terre

Velocity fluctuations of a crack front during slow propagation: an experimental approach

Optical and acoustic tracking of a crack front propagation in a heterogeneous material

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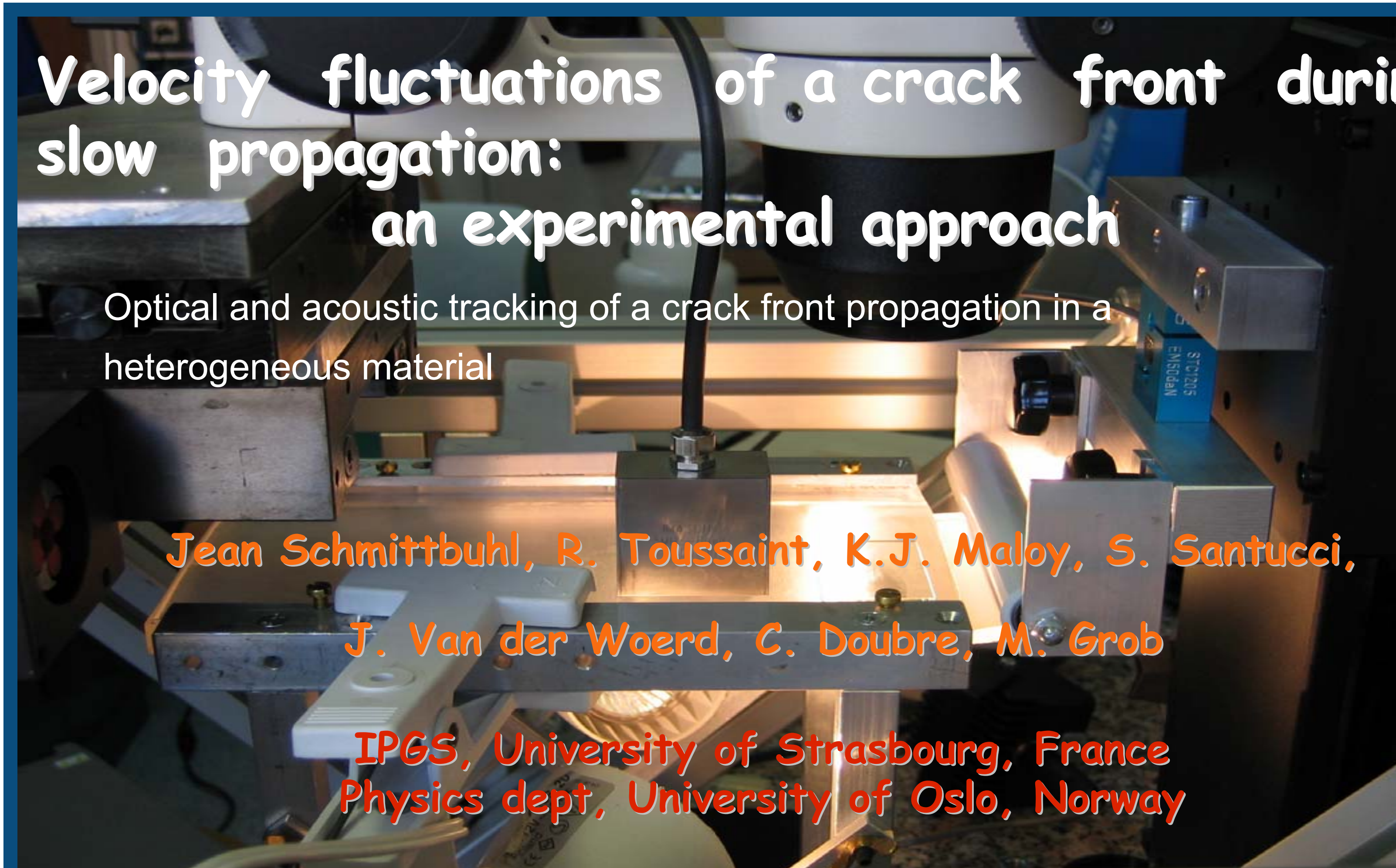
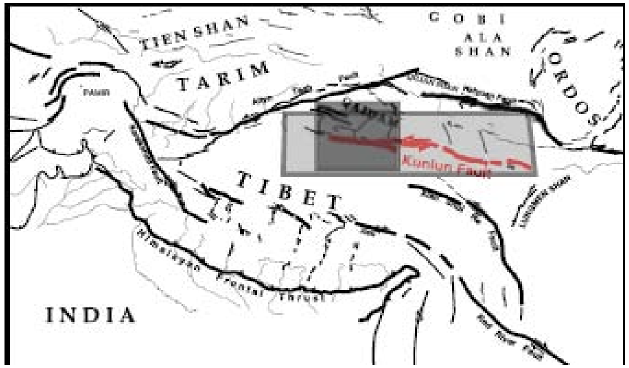


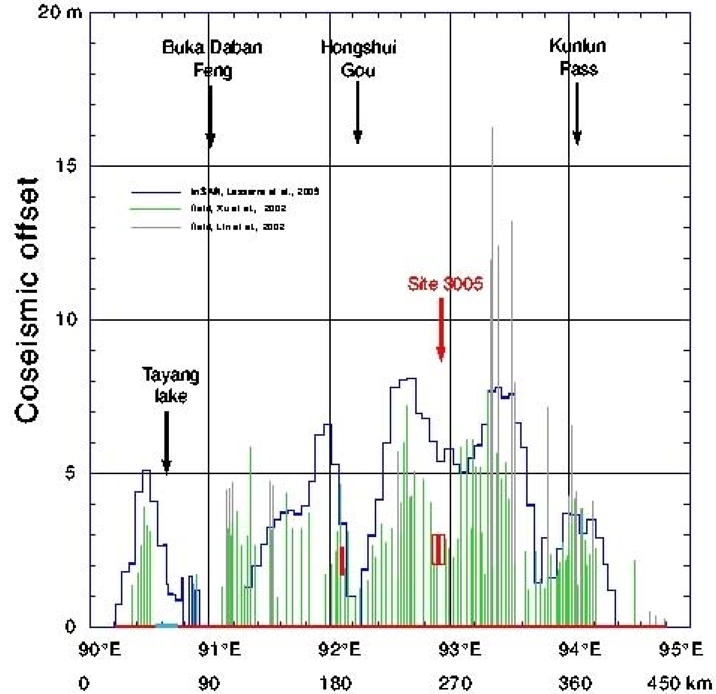
Motivations: fault slip distribution

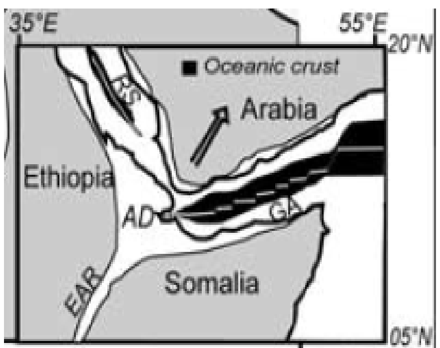
Lasserre et al, JGR, 2005

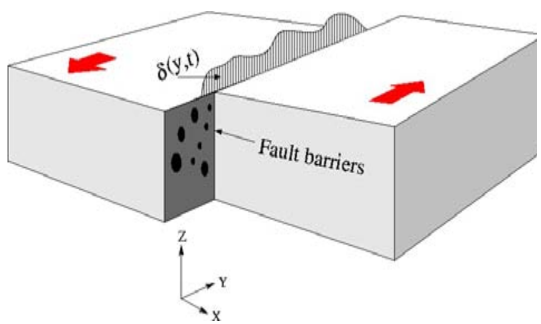
Kunlun Fault, 2001 EQ

(co-seismic slip)





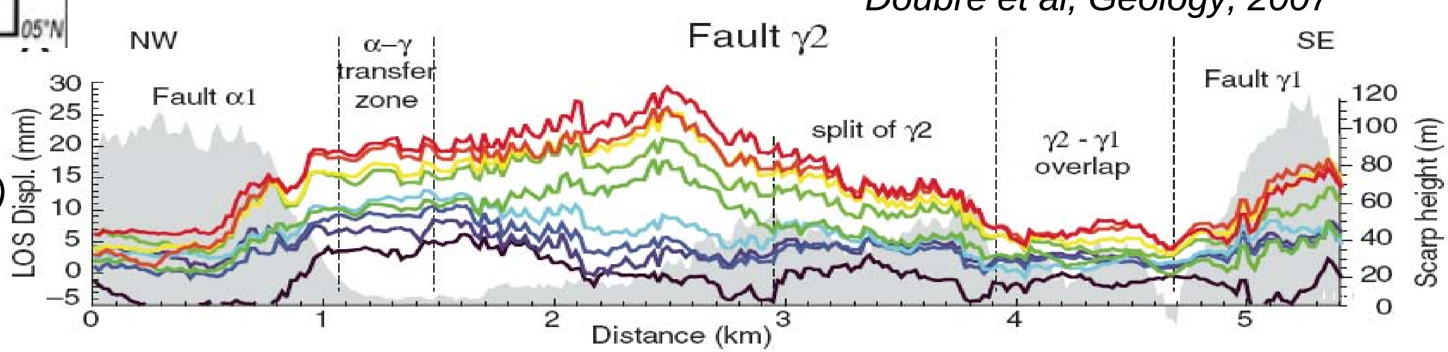




Doubre et al, Geology, 2007

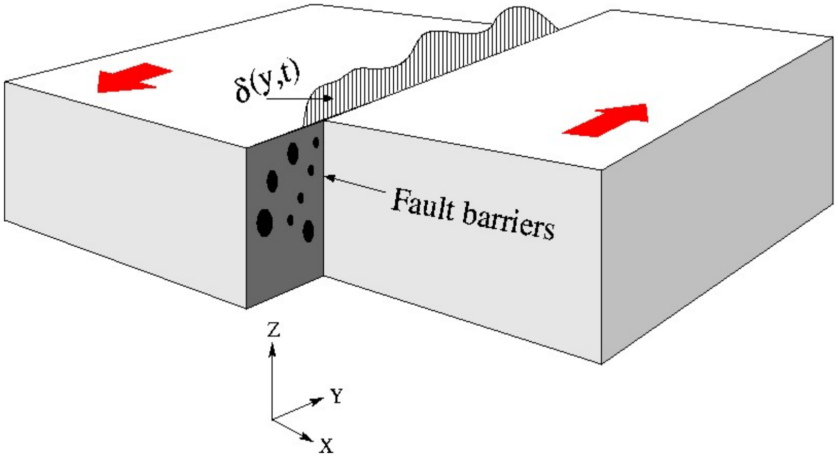
Asal Rift Faults, InSAR

(1997-2005 slip history)



2D Plane shear rupture:

2D PLANE SHEAR RUPTURE



AN EQUIVALENT PROBLEM

$\delta(y,t) \leftrightarrow a(x,t)$

$\tau(y,t) \leftrightarrow G(x,t)$

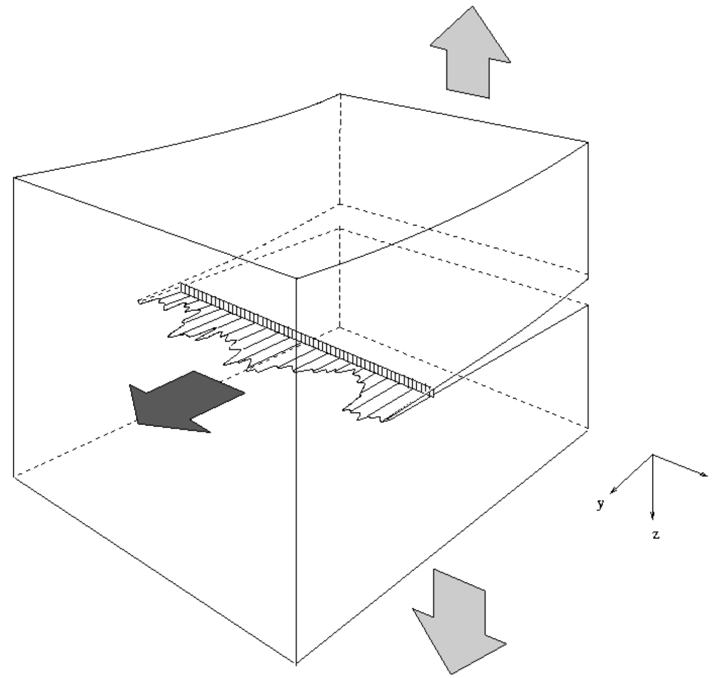
$\tau_c(y,\delta(y,t)) \leftrightarrow G_c(x,a(x,t))$

A similar elasto-dynamic kernel

$$\tau(y,t) = \frac{\mu}{2\pi}\int J(y-\xi,t)\,[\delta(\xi,t)-\delta(y,t)]\,d\xi$$

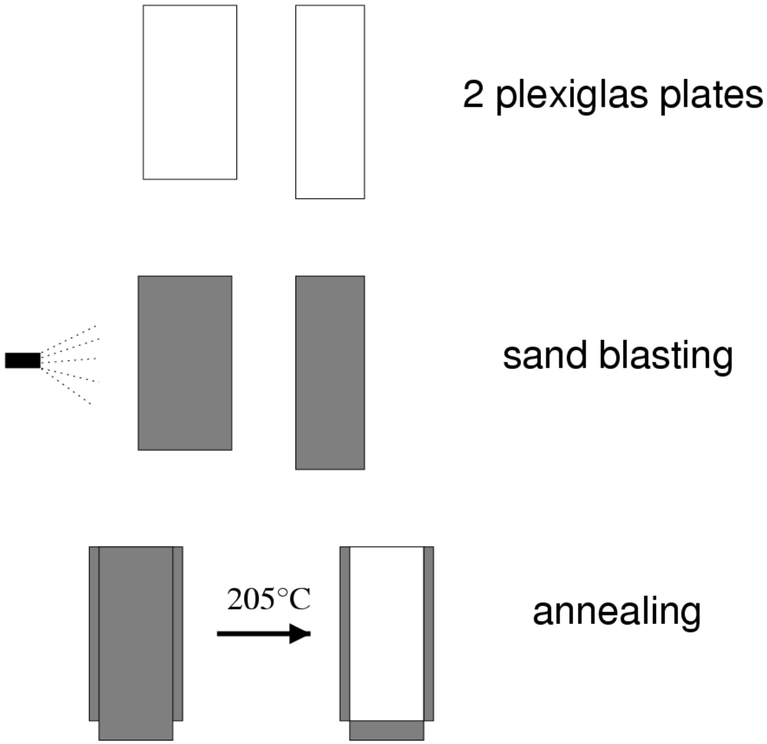
$$\frac{G(x,t)-G^{\infty}}{G^{\infty}} = \frac{1}{\pi}\int J(x-\xi,t)\,[a(\xi,t)-a(x,t)]\,d\xi$$

Quasi-static limit: $J(x,t) = \frac{1}{x^2}$

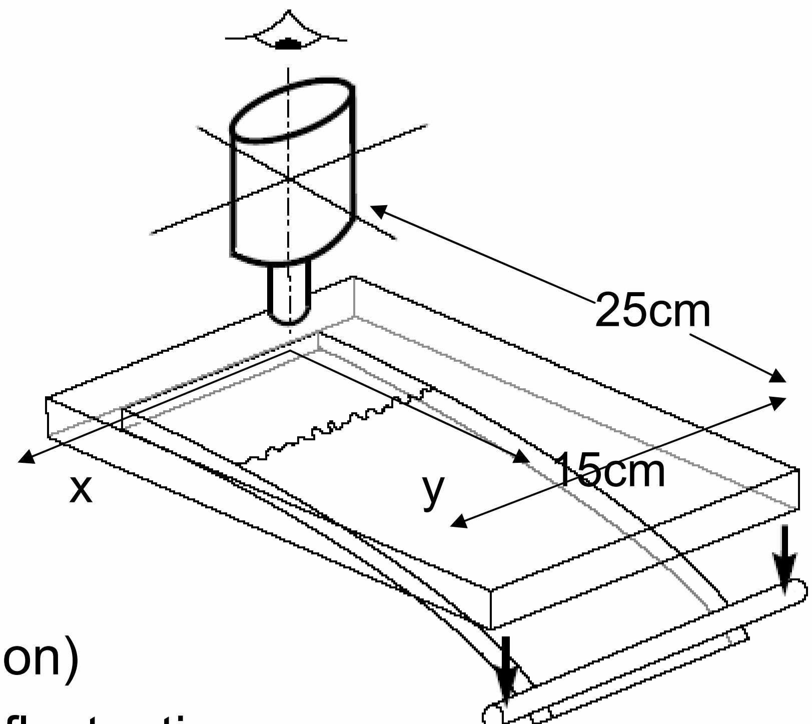


MODE I INTERFACIAL CRACK PROPAGATION

Experimental setup



- Stable crack
- Optical image recording

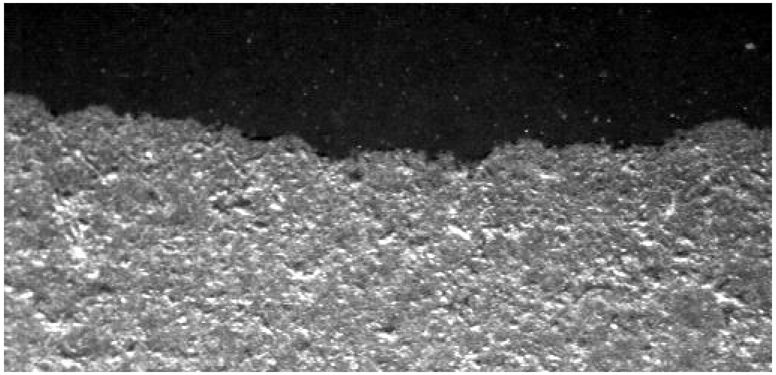


- Transparent PMMA (optical resolution)
- Sandblasting introduce toughness fluctuations
- Annealing (homogeneous material – no glue)

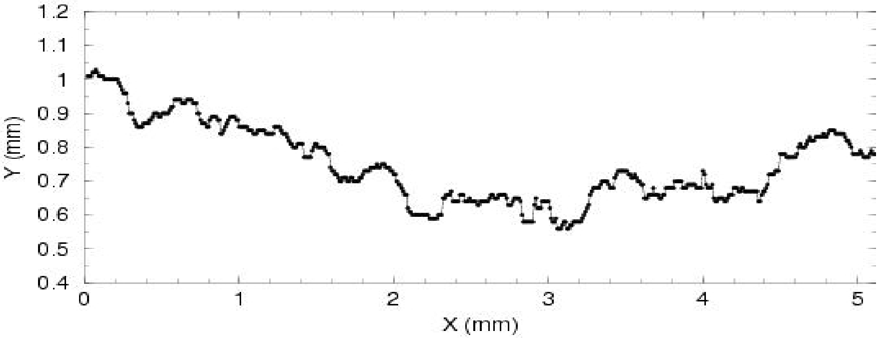
Crack front description

IMAGE ANALYSIS

Raw image



$a(x,t_0)$

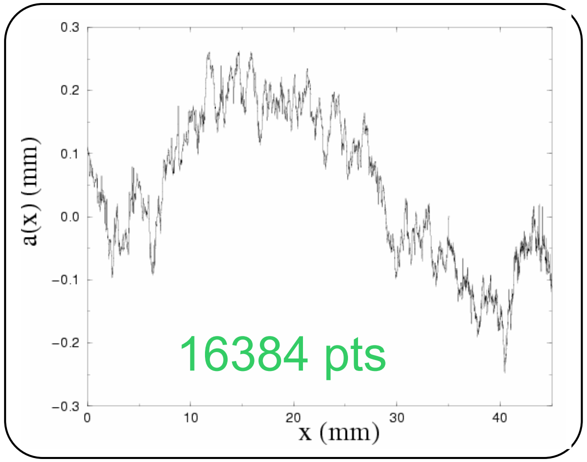


Front extraction

At rest

Long range correlations

at rest

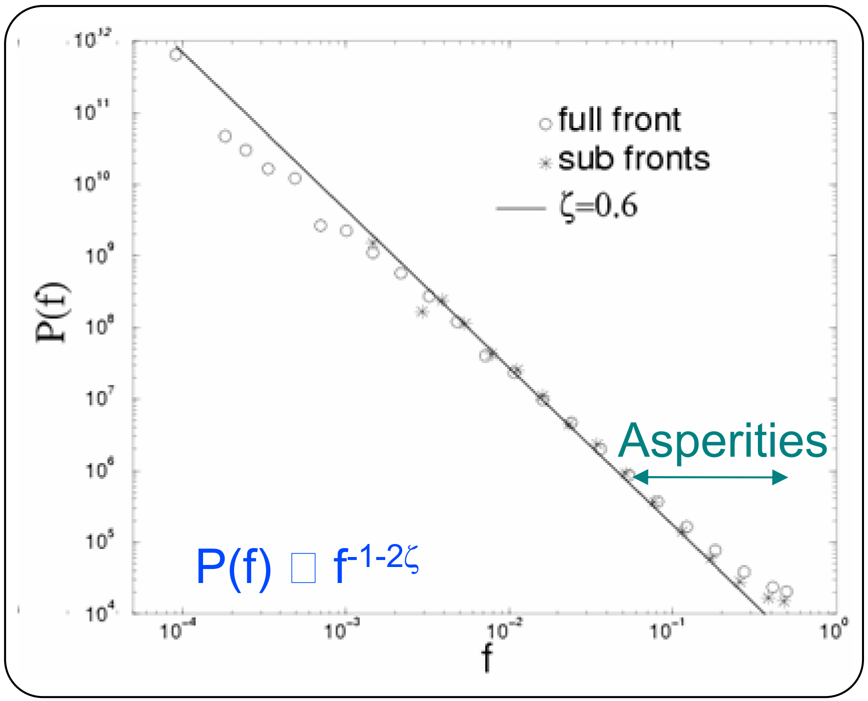


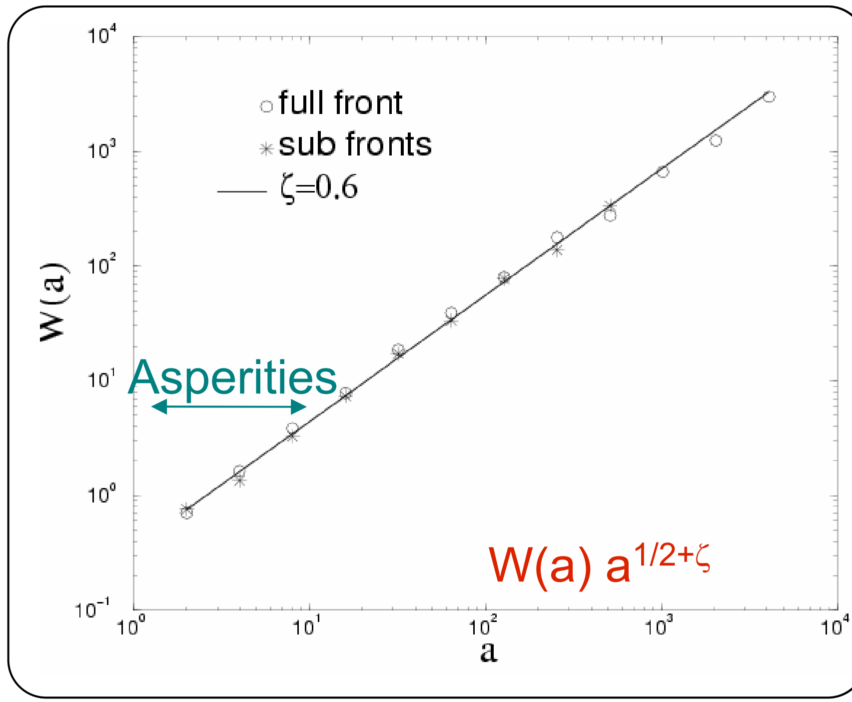
Self-affine scaling invariance

$\zeta \simeq 0.6$

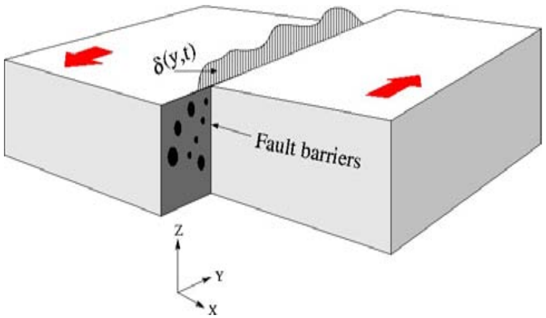
(3 $^{1/2}$ orders of magnitues)

Asperities (<50 µm = 20 px)





IMPLICATION FOR SLIP DISTRIBUTION



An analogical model: Self-affine slip distribution with H=0.6

$P_{\delta}(k) \sim k^{-2.2}$ (close to a « k-squarre model)

(e.g. Herrero and Bernard, BSSA, 1994)

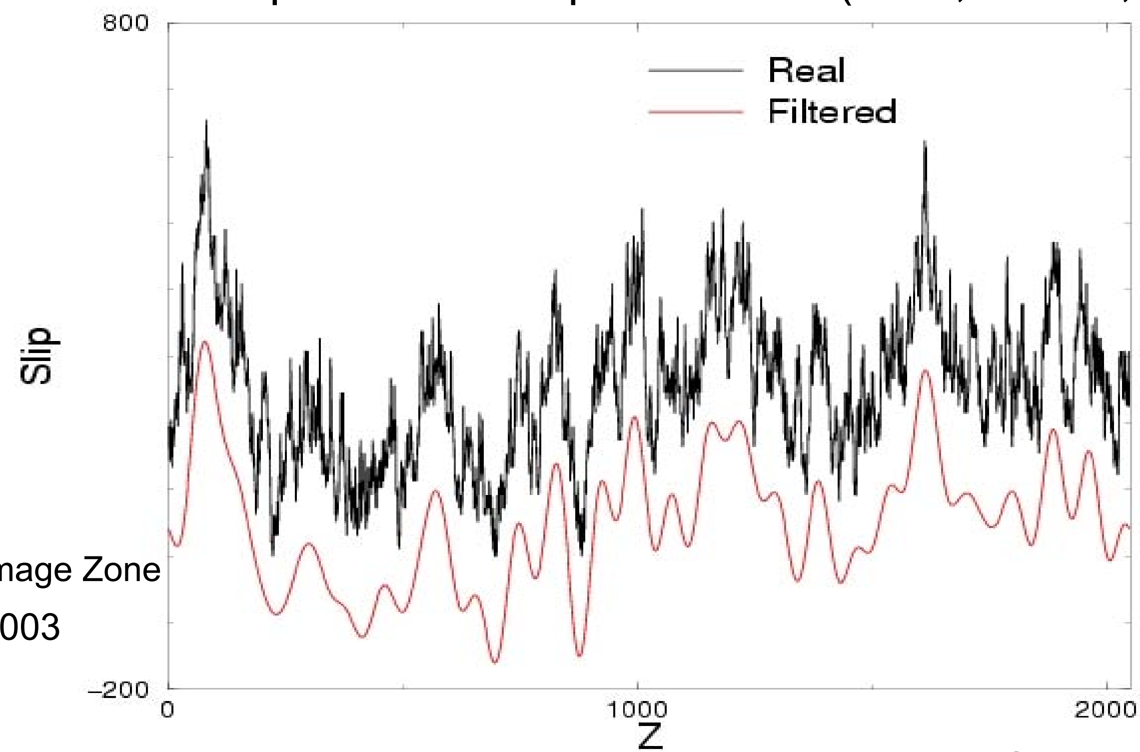
Interpretation of slip inversions (GPS, InSAR, ...)

AN EQUIVALENT PROBLEM

$$\delta\,(y,t) \leftrightarrow a(x,t)$$

$$\tau\,(y,t) \leftrightarrow G(x,t)$$

$$\tau_c(y,\delta\,(y,t)) \leftrightarrow G_c(x,a(x,t))$$



Theoretical model:

Stress-Weighted Percolation in the Damage Zone

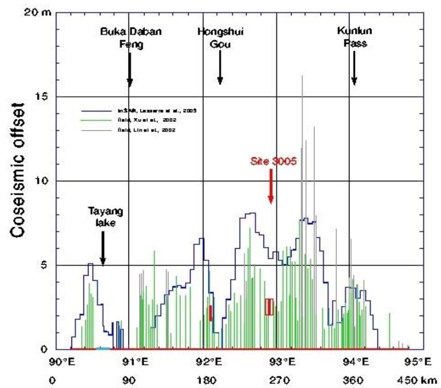
Schmittbuhl et al, PRL, 2003

Asperity size ?

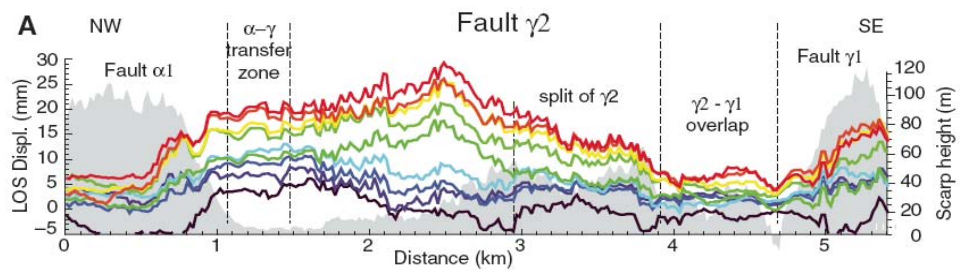
Institut de Physique du Globe de Strasbourg

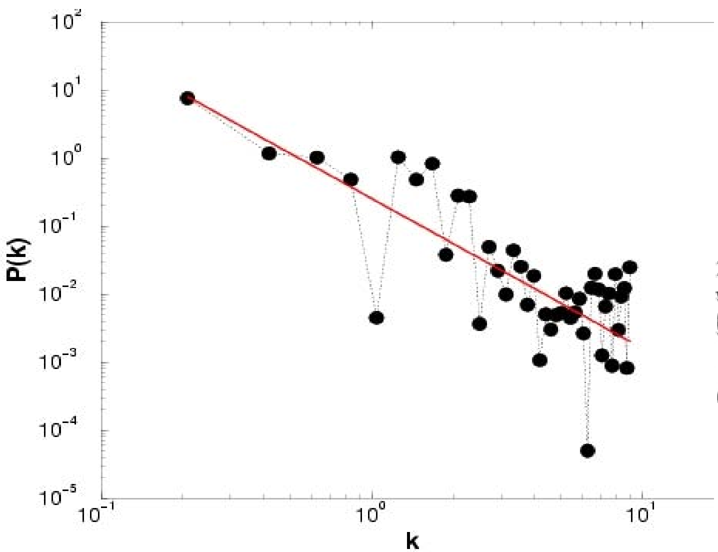
Comparison with fault slip distributions

Kunlun Fault, 2001 EQ

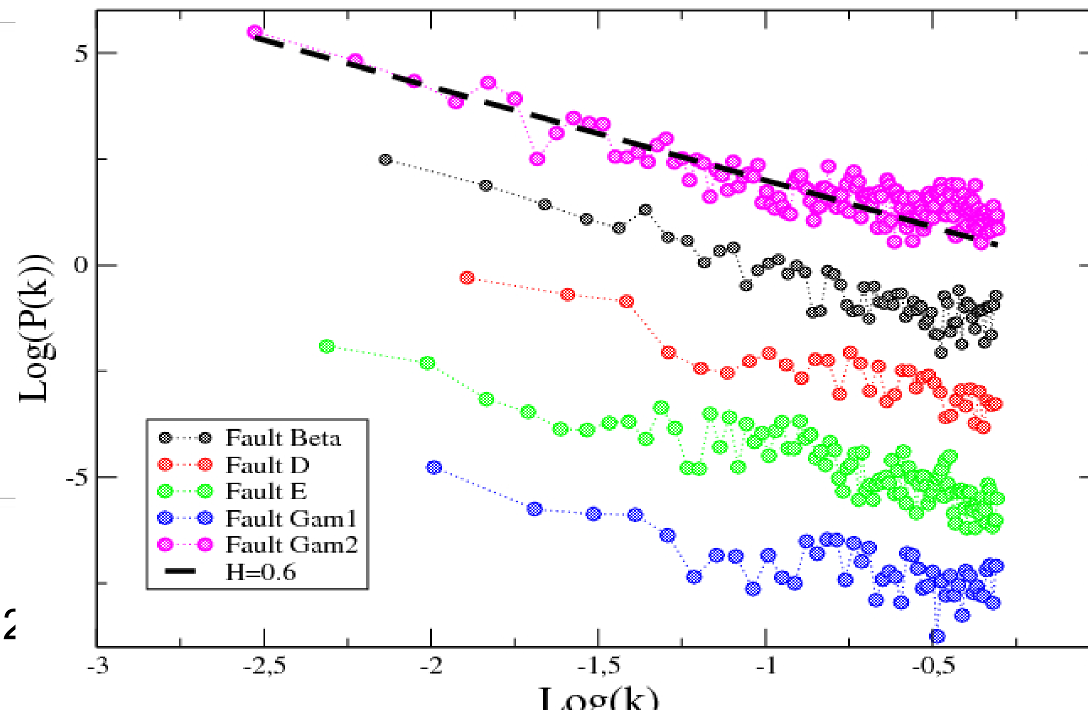


Asal Rift Faults, InSAR

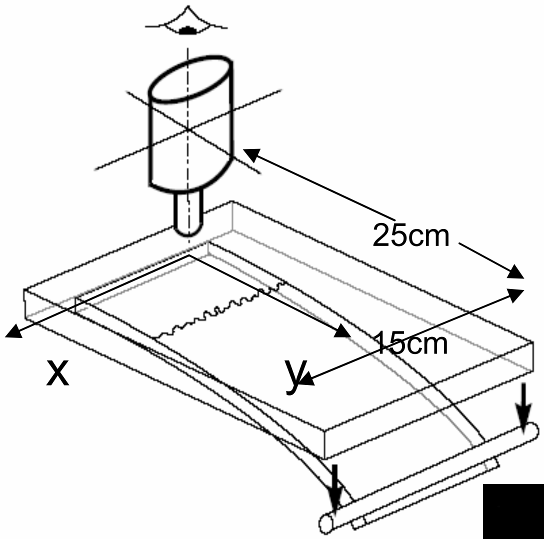




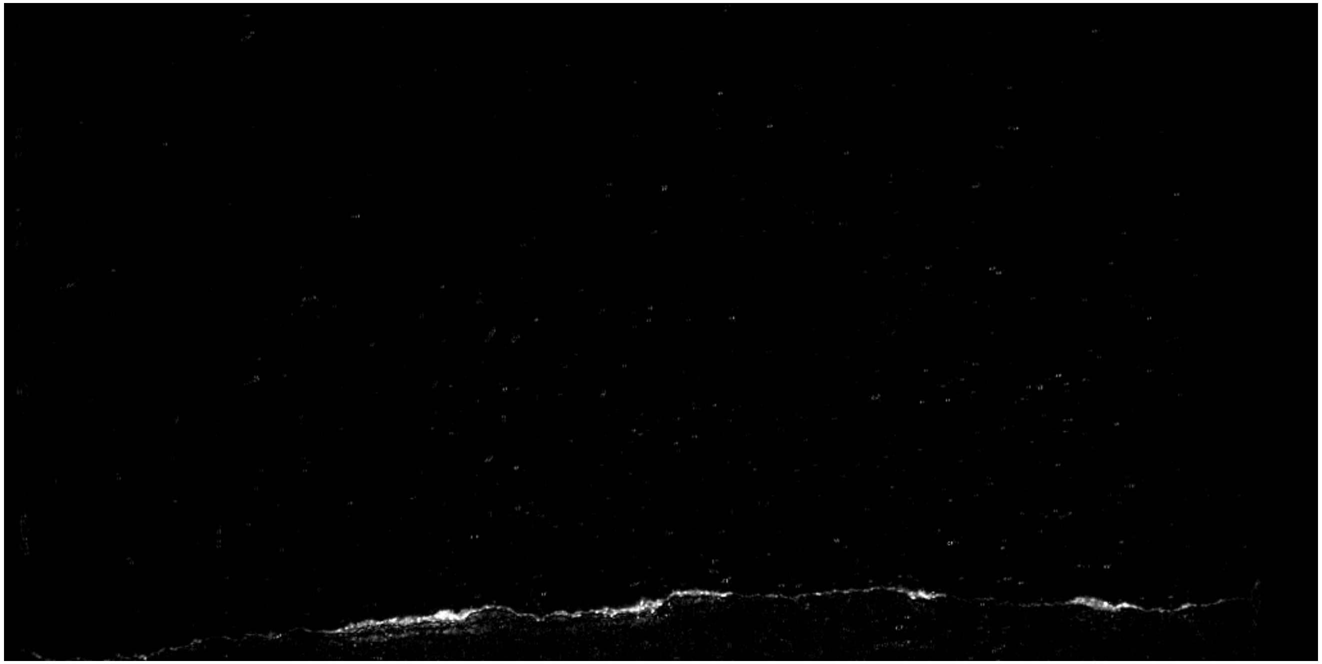
$P_\delta(k) \sim k^{-2.2}$



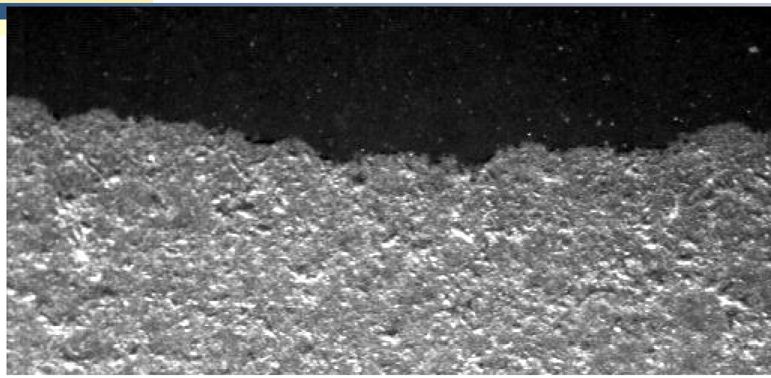
Crack front dynamics



Add a fast camera: 2000 im/sec

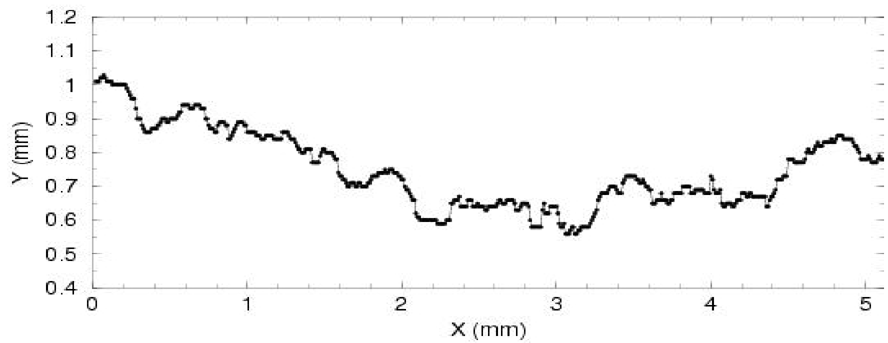


Crack front propagation



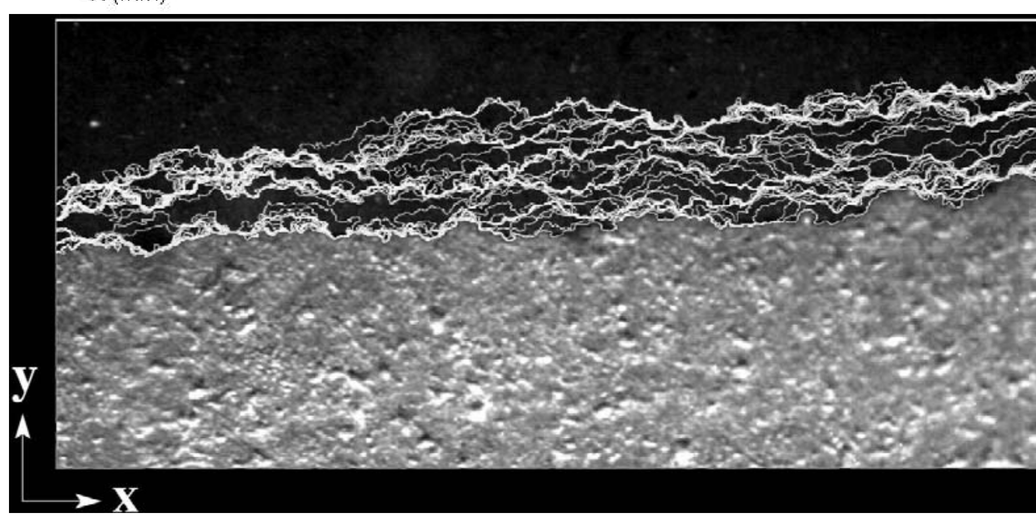
Raw image

IMAGE ANALYSIS



Front extraction

$a(x,t_0)$



Time record

(fast camera)

$a(x,t)$

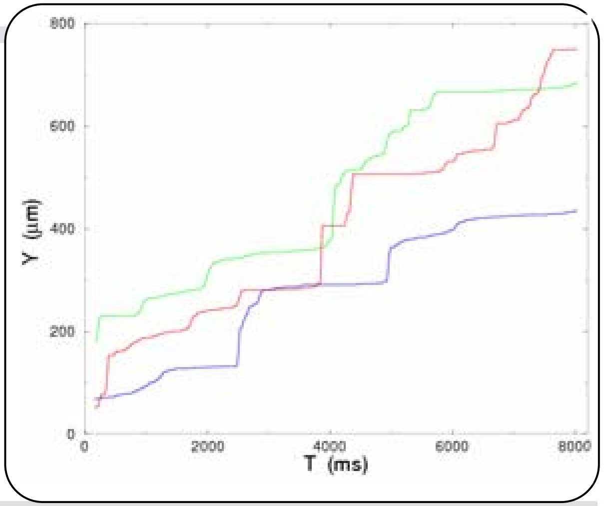
Local velocity field

During propagation...

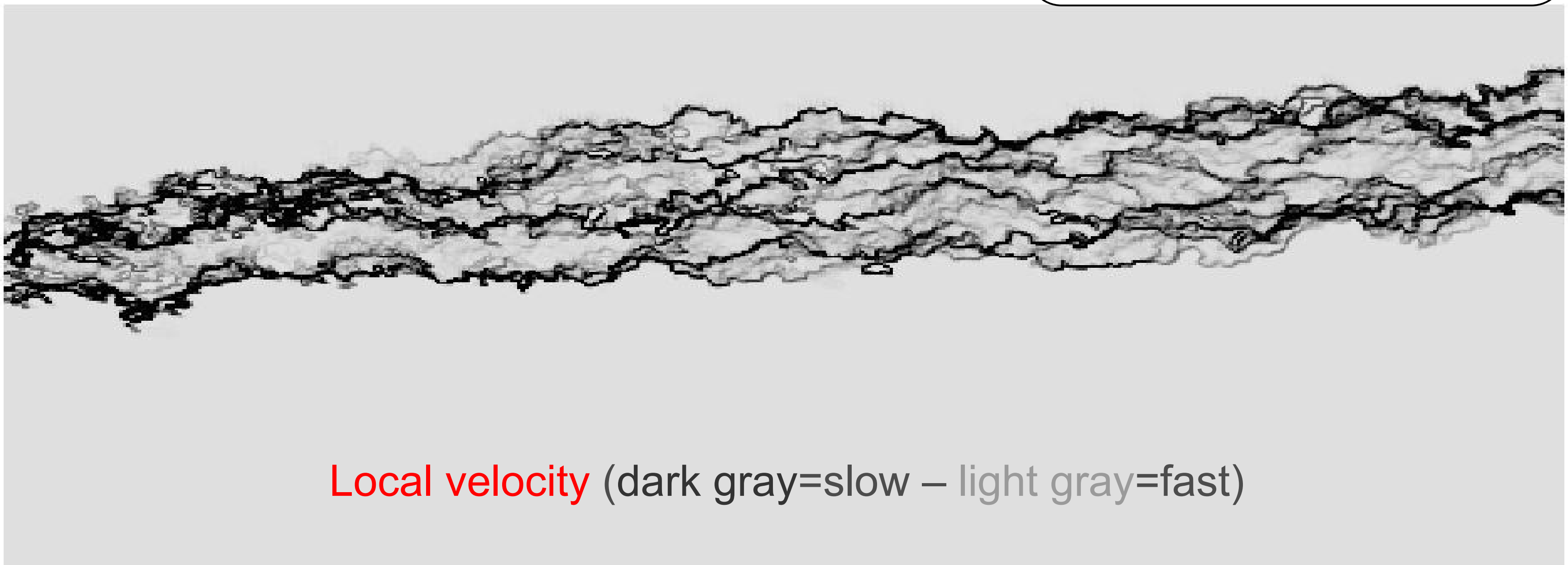
Front height a(x,t)

or

Slip evolution δ(x,t)



Space and time variability (optical resolution)



Local velocity (dark gray=slow – light gray=fast)

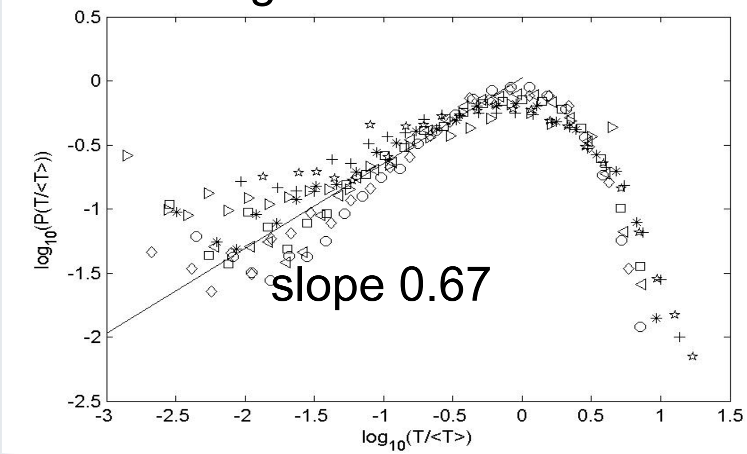
Y

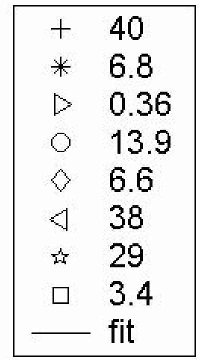
X

Measured from the waiting time: $$V_{ij} = a / T_{ij}$$

Velocity distribution

Wating time distribution





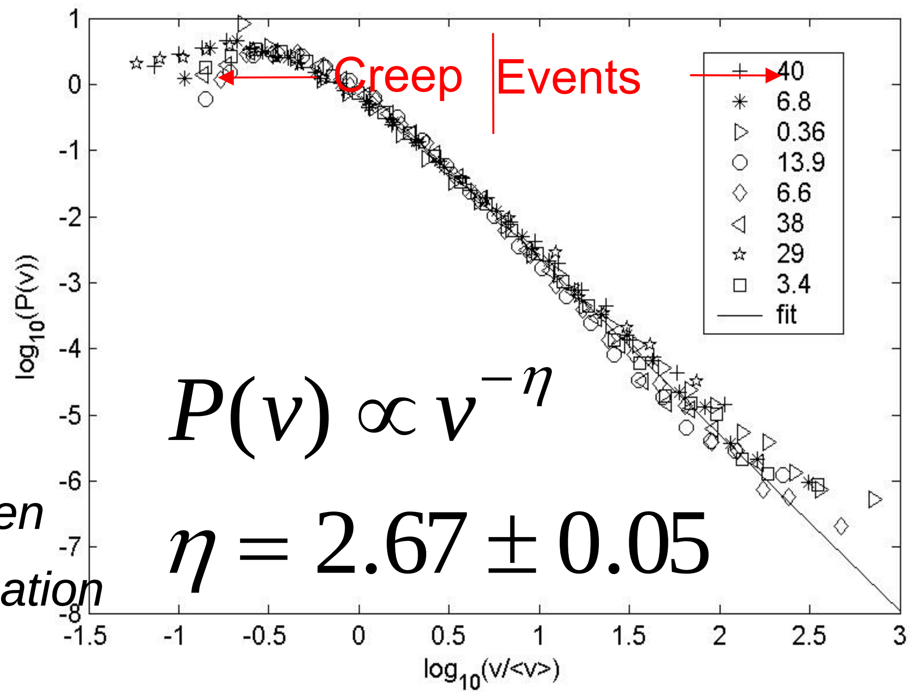
Average loading velocity <v> in µm/s.

Each curve corresponds to more than $2 \cdot 10^6$ waiting times.

Depinning | Pinning

$$V_{ij} = a / T_{ij}$$

Velocity distribution



$$P(v) \propto v^{-\eta}$$

$$\eta = 2.67 \pm 0.05$$

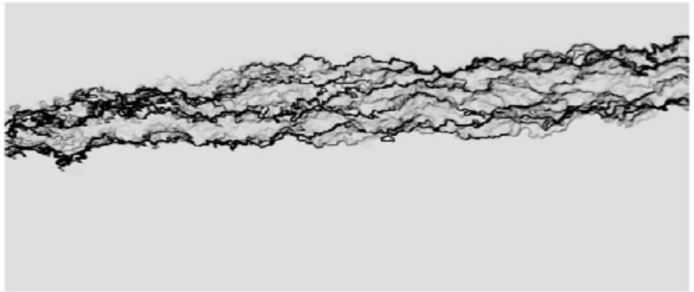
No clear transition between

fast and slow propagation

No mean crack velocity…

Event definition and distribution

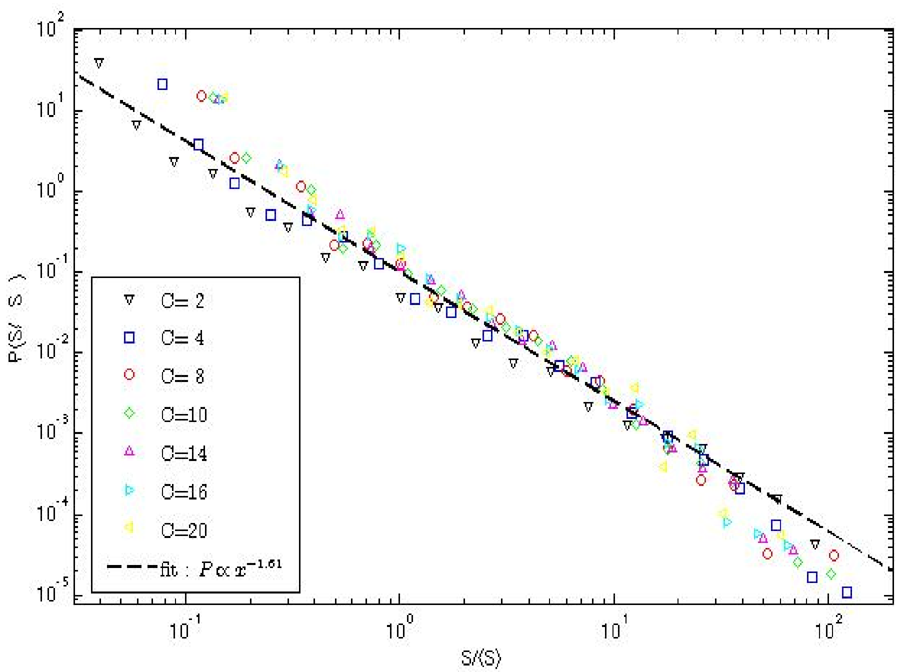
Local velocity matrix



Event definition

Clipped image of the velocity distribution (C <V>)

Event size distribution



$$N(s) \propto s^{-\gamma}$$

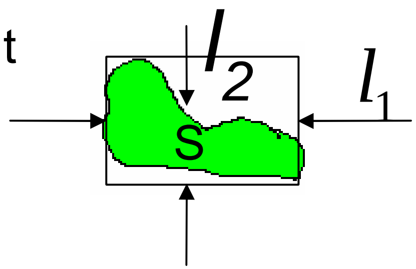
$$\gamma \approx 1.65$$

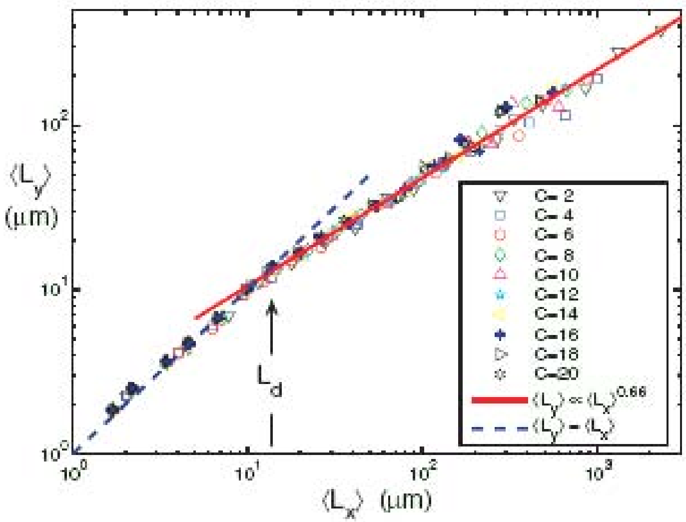
Gutenberg-Richter: $(s \sim M_0)$

$$N(M_0) \sim M_0^{-1.66}$$

Event shape

Aspect ratio of the event





$$l_2 \propto l_1^{\,\mu}$$

$\boxed{\mu = 0.66}$

Consistent with roughness exponent ζ=0.64

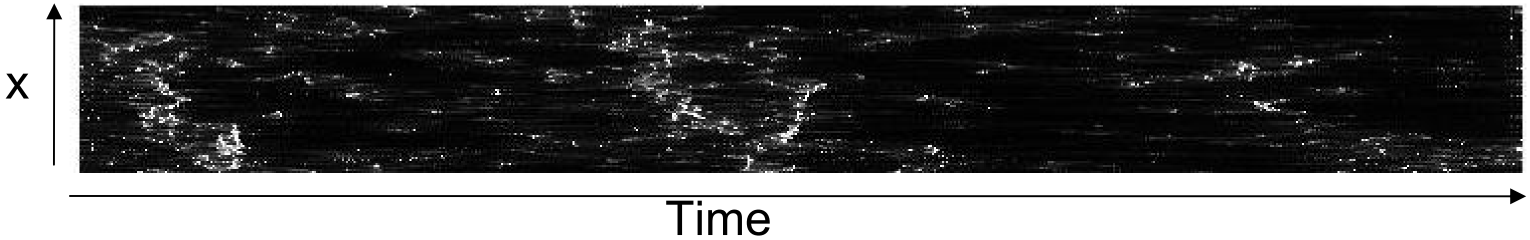
Counterpart in fault activity: l_1, rupture length,
l_2, maximum slip

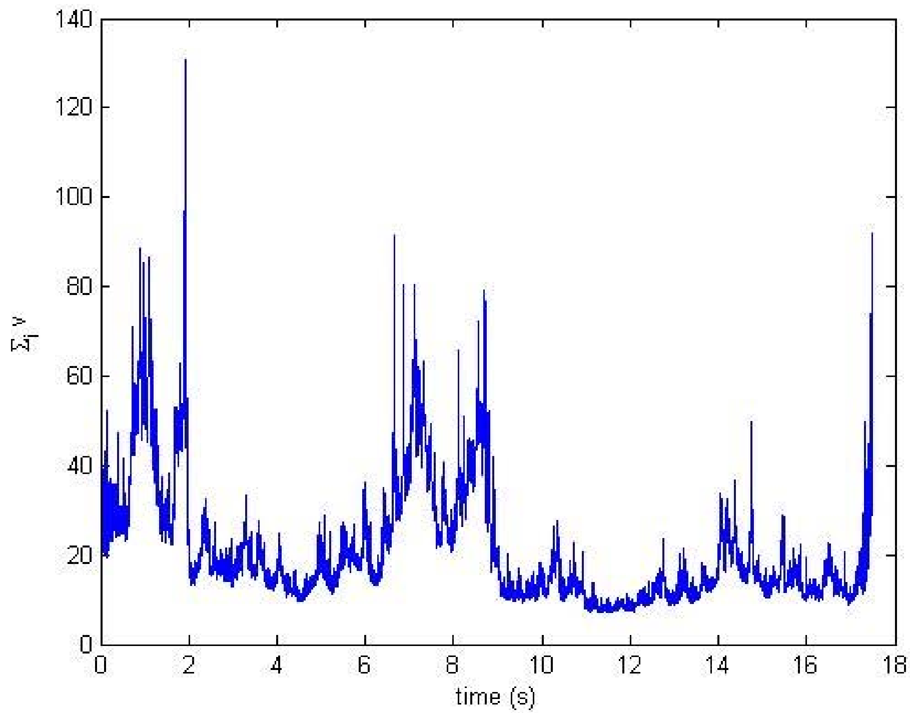
Evidence of scaling?

$$l_2 \propto l_1^{\,\mu}$$

Time fluctuations

Average velocity and fracture activity

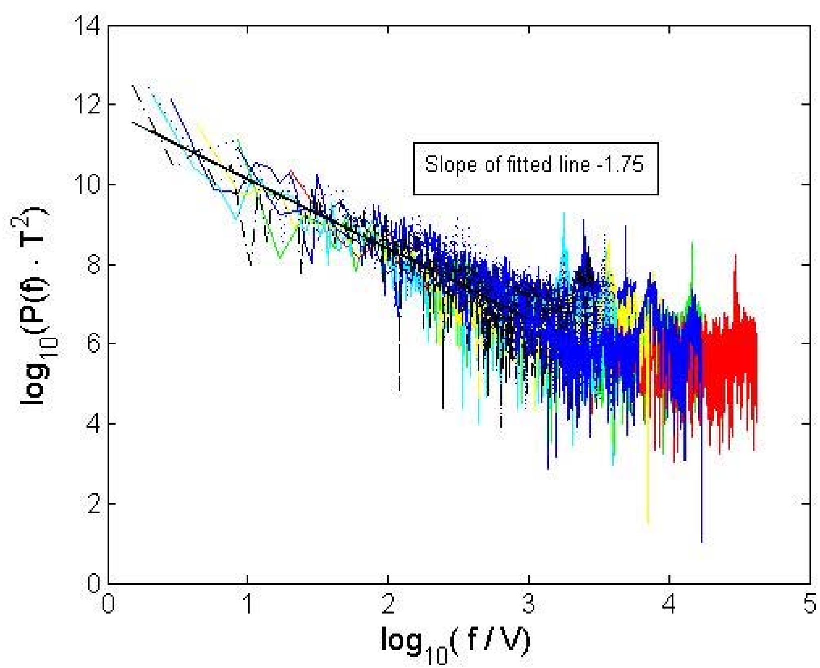




Average front velocity vs time

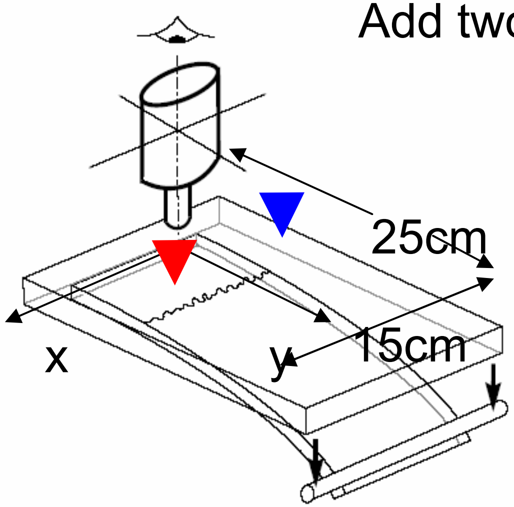
Power spectrum

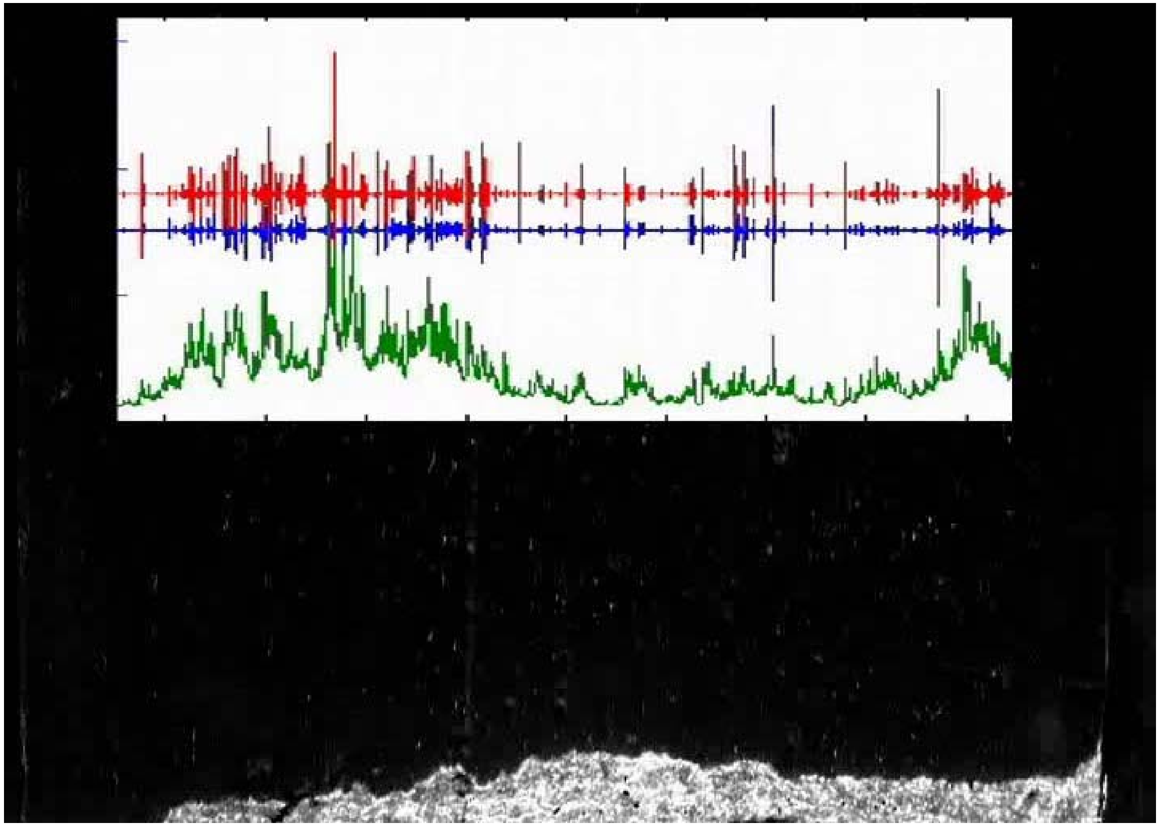
Slope: -2H – 1 H=0.38



Acoustic emissions

Add two acoustic sensors (1MHz)





Conclusions

- Modeling of strongly heterogenous fault (>1000 random barriers) over a large time period (broad dynamics: from slow to fast events)
- Analogy between 2D plane rupture and mode I crack
- An experimental approach: Tracking of an interfacial crack front
- Artificial barrier disorder: Uncorrelated sand-blasting (small scales)
- Self-affine fracture front (i.e. highly spatially correlated) : $\zeta = 0.63$
- A quasi «k» model: $P_\delta(k) \sim k^{-2.2}$
- Rich event dynamics: fast camera (1000 images/sec)
- Velocity fluctuations with power law distribution: $P(V) \sim V^{-2.67}$
- No sensitivity to the average crack velocity: 1 order of magnitude
- Burst size distribution: $N(S) \sim S^{-1.65}$
- Seismic moment distribution: $N(M^I_0) \sim {M^I_0}^{-1.65}$ (slow dynamics – optical estimates)
- Origin of the Gutenberg-Richter distribution: $N(M_0) \sim M_0^{-1.66}$
  No underlying distribution of the barriers (random barriers)
- Perspectives: Simultaneous acoustic and optical monitoring, event catalogs, space-time correlation of epicenters, memory effects, nucleation of big events